

Comments on the Process and Product of the Health Impacts Assessment Component of the National Assessment of the Potential Consequences of Climate Variability and Change for the United States

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In 1990 Congress formed the U.S. Global Change Research Program and required it to conduct a periodic national assessment of the potential impacts of climate variability and change on all regions and select economic/resource sectors of the United States. Between 1998 and 2000, a team of experts collaborated on a health impacts assessment that formed the basis for the first National Assessment's analysis of the potential impacts of climate on human health. The health impacts assessment was integrated across a number of health disciplines and involved a search for and qualitative expert judgment review of data on the potential links between climate events and population health. Accomplishments included identification of vulnerable populations, adaptation strategies, research needs, and data gaps. Experts, stakeholders, and the public were involved. The assessment is reported in five articles in this issue; a summary was published in the April 2000 issue of *Environmental Health Perspectives*. The assessment report will enhance understanding of ways human health might be affected by various climate-associated stresses and of the need for further empirical and predictive research. Improved understanding and communication of the significance and inevitability of uncertainties in such an assessment are critical to further research and policy development. *Key words:* assessment, climate change, global warming, human health impacts, integrated assessment, policy, risk assessment, uncertainty. — *Environ Health Perspect* 109(suppl 2):177–184 (2001).

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Between the summers of 1998 and 2000, a group of health researchers from academia, federal agencies, and the private sector, including the authors of this article, collaborated on an assessment of the potential health impacts of climate variability and change on the United States. An executive summary of this effort was published in *Environmental Health Perspectives* in April 2000 (1). This summary also formed the basis for Chapter 15 of the report of the National Assessment of the Potential Consequences of Climate Variability and Change for the United States (2). This issue of *Environmental Health Perspectives* contains the underlying analyses of the five health outcomes that were the focus of the health impacts assessment: temperature-related morbidity and mortality (3); health outcomes associated with extreme weather events such as storms and floods (4); health outcomes associated with air pollution (5); water- and food-borne diseases (6); and vector- and rodent-borne diseases (7).

In this article, we first provide context with a brief discussion of climate change and of the National Assessment of the Potential Consequences of Climate Variability and Change for the United States (National Assessment), of which the health impacts assessment was a component. Second, we identify methodologies available to assess environmental risks to human health as well as the methods chosen for the health impacts assessment. Third, we describe the process and product of the health impacts assessment

in the context of research and policy making on climate change in the United States.

The U.S. National Assessment

As used in this paper and commonly, the term *climate change* is understood to encompass surface temperature changes on global, regional, and local scales as well as changes in the mean and variability of precipitation, wind patterns, and possibly ocean currents (8). The broadest understanding of the term—and that used by the Intergovernmental Panel on Climate Change (9,10) and within the context of the health sector assessment—encompasses natural climate change as well as change that may result from anthropogenic emissions of carbon dioxide and other “greenhouse” gases (so called because they trap heat within the earth’s atmosphere). [In some contexts, most notably the United Nations 1992 Framework Convention on Climate Change (11), the term *climate change* is defined more narrowly as “a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere,” which occurs “in addition to natural climate variability observed over comparable time periods.” This distinction is important for policy development, but the broader definition is more useful in understanding the potential consequences for human health of combined changes in climate.]

The mean global surface temperature has warmed 0.7–1.4°F over the past 100 years

(12–14). In the contiguous United States, temperatures have increased by approximately 1°F (15). Historical data support the theory that an altered hydrologic cycle will accompany warming of the earth’s surface (16–18). For example, precipitation has been increasing in the United States, with much of the change due to increases in heavy-precipitation events (more than 5 cm per day) and decreases in light-precipitation events (15,19,20). Such changes are likely to have significant regional consequences. Methods to project changes in climate over time are being rapidly improved upon, and over time they have become more complicated, more accurate, and better at downscaling, which makes them more useful for regional adaptation planning purposes (21).

The National Assessment was mandated by Congress in the Global Change Research Act of 1990 (22), under which the U.S. Global Change Research Program (USGCRP) was formed (23). During the past decade, the USGCRP has funded scientific research by a number of federal agencies within the Departments of Agriculture, Commerce, Energy, Interior, and Health and Human Services; the U.S. Environmental Protection Agency (U.S. EPA); the National Science Foundation; the National Atmospheric and Space Administration (which also receives funding for space-based observation programs); and the Smithsonian Institution (24). Most of the funding goes to research on global-scale atmospheric, oceanic, and earth processes, with a reported 1.5% of the decade’s global change research budget spent on studying the potential societal impacts of and adaptation to global change (25). In its fiscal year 2001 report to Congress, the USGCRP said it would in the future augment the global-scale physical science research that

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has predominated its work with more research on the interrelationships among global environmental impacts, and the global, regional, and local impacts of these events (24).

Congress required the USGCRP to periodically (at least every 4 years) conduct a national assessment of the impacts of climate variability and change that “1) integrates, evaluates, and interprets the findings of the Program and discusses the scientific uncertainties associated with such findings; 2) analyzes the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity; and 3) analyzes current trends in global change, both human-induced and natural, and projects major trends for the subsequent 25 to 100 years” (22). Responsibility for undertaking the assessment was given to the National Science and Technology Council (NSTC), a Cabinet-level council formed in 1993 to coordinate the science and technology policy making of the federal government. In 1998 the President’s Science Advisor, as executive secretary of the NSTC, requested that the Subcommittee on Global Change Research (SGCR) of the NSTC’s Committee on Environment and Natural Resources conduct the first National Assessment of the consequences of global climate variability and change (26). On behalf of the SGCR, the National Science Foundation established a 14-member National Assessment Synthesis Team (NAST) under the Federal Advisory Committee Act (27). The NAST developed a plan for the National Assessment that was approved by the SGCR and the NSTC (23).

The National Assessment was organized in multiple, overlapping layers of analysis, with assessment teams from several geographic regions and from five economic or resource sectors (forestry, agriculture, water resources, coastal zone, and human health). One group distinct from the regional and sectoral categories was the Native Peoples, Native Homelands group, the geographic scope of which was national, but which otherwise addressed the range of sectoral issues, with a special focus on how climate change might affect indigenous interests. Funding for the various assessments was distributed among several federal agencies.

The National Assessment process was designed to involve “stakeholders,” an undefined term that encompassed representatives from the federal and state, local, and tribal governments, as well as from industry, academia, nonprofits, labor, and the general public (23). Three categories of product were envisioned: national synthesis documents, sectoral analyses, and regional analyses. The first National Assessment was intended to

look at possible impacts of climate variability and change for two time periods: over the next 25–30 years, and over the next 100 years. The overall goal was to address a series of questions (23):

- What are the current environmental stresses and issues that form the backdrop for potential additional impacts of climate variability and change?
- How might climate variability and change exacerbate or ameliorate existing problems?
- What coping options exist that can build resilience to current environmental stresses and also possibly lessen the impacts of climate change?
- What are the priority research and information needs (near- and long-term) that can better prepare managers, policy makers, and the public to reach informed decisions related to climate variability and change?

Ideally, each analysis was to be quantitative, incorporating specified climate and socioeconomic scenarios. The analyses were also intended to reflect a range of expert opinions, with careful recognition of risks and uncertainties (23). The NAST’s output, the National Assessment Synthesis Report, consisted of two separate documents, the Foundation Document and the shorter Overview Document (28). The Synthesis Report went through two rounds of technical peer review and a 60-day public review period (26). The USGCRP states that the National Assessment will help direct future USGCRP activities that focus less on “observing and documenting change in the Earth’s physical systems,” and more on “a broader research effort that also includes improved understanding of how global change will affect the Earth’s biological systems—and the human societies that are dependent on them—and making useful scientific data and information more broadly available for public and private planning and decisionmaking” (24). Further discussions of the National Assessment as a whole and of individual components other than the health impacts assessment are beyond the scope of this article.

Methods for Assessment of Environmental Risks to Human Health

Approaches to evaluating the impacts of environmental risks to human health vary greatly, depending on the extent of knowledge about the key variables of concern, such as exposure risk and susceptibility factors, and on the certainty and nature of the relationship between the risk and the potential outcomes. Probably the most familiar method is that of toxicologic risk assessments of population exposures to environmental agents, generally chemicals. The standard four-step risk assessment paradigm—hazard identification, dose–response

assessment, exposure assessment, and risk characterization—was formulated by the National Research Council in 1983 (29) and later refined (30,31). Under this paradigm, the evaluation of information about the hazardous properties of environmental agents and about the extent of human exposure to them produces a quantitative or qualitative statement about the probability and degree of harm to the exposed populations (30). Inevitable policy judgments about choice of scientific approach are made in each of the four steps. For example, the choice of one dose–response model over another is such a choice (31).

As risk assessment has evolved, its general approach and philosophy have become more relevant to complex environmental problems. Whereas early risk assessments focused on determining a probability of harm, later efforts considered social, economic, and political factors in describing risk (30). Stakeholders are now expected to be involved throughout risk assessment to ensure that the risk characterization addresses a broad range of concerns and that the context in which the assessment will be used is taken into account (30–32). Risk assessment methodologies have developed to evaluate noncancer risks to human health, such as neurotoxicologic effects (33), as well as risks to ecologic systems (33,34).

Although traditional risk assessment theories and methodologies are informative, the process of estimating the potential effects on health of specific projected climate scenarios differs in important ways from quantitative risk assessment (35). One critical distinction is the inapplicability of the primary assumptions underlying risk assessment—that a defined exposure to a specific agent (generally a xenobiotic) causes an adverse health outcome to identifiable exposed populations, including specific people at particular risk. The health outcome for some toxic exposures is distinctive, and the association between immediate cause (e.g., asbestos exposure) and health impact (e.g., mesothelioma) can be determined fairly clearly. Even where the health outcomes are less specific than in the asbestos example, data may demonstrate the outcome of concern through animal or epidemiologic studies that show an increased relative risk associated with a well-defined exposure. Most diseases associated with environmental exposures, however, have many causes, which may be interrelated. These multiple, interrelated causes as well as relevant feedback mechanisms must be addressed when investigating complex disease/exposure associations because they may limit the predictability of the health outcome and even the ability to estimate the degree of uncertainty in any efforts made at projection. Environmental epidemiology, which aims to examine holistically the

relationship between the environment and human health, has developed several nontraditional methods of data analysis to deal with these complexities.

With climate change, the uncertainty associated with the lack of specificity of outcome is compounded by the fact that both the relevant exposure and susceptibility factors vary depending on which of several potential health effects are being considered and, more generally, on an unquantifiable number of complex modifying or interacting factors. With respect to exposure, at the furthest causal point there is uncertainty about the magnitude, timing, and nature of changes in the climate system, and thus a need to estimate the potential impacts of a range of possible climate scenarios on health (35). Closer in on the causal web linking climate events or exposures to health, many of the potential health impacts of climate change are indirect or nonlinear. As noted, some environmental health outcomes, such as water-borne gastroenteritis and air pollution-associated respiratory impacts, are not easily linked to an immediate (proximate) causal exposure, let alone to points in a wider causal web such as municipal wastewater management or transportation infrastructure investments. Global climate change is an even more distant variable in the causal web. Improved understanding of climate-related determinants of health will require recognition of an ecosocial framework for epidemiologic theory (36), i.e., a social-ecologic system perspective rather than the traditional epidemiologic focus on proximate, individual-level risk factors (37). Ecology can be defined in this context as “the formal study of the interrelations between groups of organisms, populations, and species and their surroundings,” including the relationships among individual humans, groups of humans, and the broader environment in which they live (37). Further complicating efforts to project an association between future climate and health is the lack of information about the current association between climate and health. There are many unresolved empirical questions about the sensitivity of particular health outcomes to weather, climate, and climate-induced changes in environmental conditions critical to health, such as water resources. There are also critical uncertainties in projections of future health status of potentially affected populations, as discussed below. In sum, measurement and estimation of the impacts of climate change entail identifying effects over a baseline, yet the human health-climate association baseline remains largely undetermined.

Thus, in the context of climate change, methodologies for assessing health risks have been proposed or used that are distinct from

the four-step risk assessment paradigm, although many of the goals and principles of that approach (such as inclusiveness and policy relevance) remain important. The most common methods are expert judgment; analogue, or historical, studies; and biophysical modeling (35,38,39), which are discussed below. These methods can be used separately or can overlap in an assessment effort.

Expert judgment includes extensive literature review and identification of comparable studies, in combination with the collective experience and judgment of a group of individuals with diverse, relevant expertise. Stakeholders should be involved throughout the assessment to provide information, concerns, and interests. Expert judgment can rapidly assess the state of knowledge concerning a problem (38). Such analyses are triggered largely by policy needs. The analogue approach uses recorded climatic regimes as analogues for the future climate of a given region (40). Analogues include historical events or trends and geographic comparisons. For example, researchers use the climate anomalies associated with the El Niño Southern Oscillation to examine the potential effects of extreme climate variability on human health. Such analogue studies have limited applicability to populations with greater or lesser vulnerability to short-term variability than the historical reference population. Similarly, with geographic analogues (such as using the current climate of St. Louis, Missouri, to project the future climate of New York City) there is usually a lack of correspondence between the two locations for other important factors, such as living standards and behaviors, that makes the value of the analogy limited. Finally, it has been suggested that future exposure patterns may vary from past experience because stochastic and nonlinear processes are typical of natural systems, and thus exposure patterns may vary in the future from historical trends (41).

Biophysical modeling can be either empirical or process based (mathematical). An empirical approach begins with quantification of current associations between risk factors and disease outcomes. Estimates of future populations and potential exposures are used to project quantitative relationships and to estimate statistical uncertainties. An example is a retrospective study of the relationships between climatic extremes and mortality in the five largest Australian cities (42). Expected numbers of heat-related deaths per day in each city were calculated. The authors then applied these relationships to scenarios for climate and demographic change to predict potential impacts on public health in the same cities in the year 2030. In another recent example of empirical modeling, researchers used a multivariate statistical

analysis to predict future distribution of malaria given future general circulation model climate scenarios. The model achieved a match of 78% when run for present-day malaria distribution and compared to current data (43,44).

Process-based (sometimes called systems-based or scenario-based) models begin with integration of what is known about the system of interest. Theoretical and empirical information about the disease of interest are derived from epidemiologic, clinical, and microlevel (molecular and genetic) studies. A model is developed to estimate the association between climate and disease under a range of potential scenarios. A benefit of these models is that they allow for integrated consideration of the combinations of environmental, biologic, ecologic, and social factors that influence health (although in practice few of these integrative analyses have been conducted). A drawback is that uncertainties accumulate. These, however, can be examined and made transparent. Applications of this approach include integrated models of disease transmission for dengue fever (45), malaria (46), and heat-related mortality (47).

Ecologic risk assessment is another approach to evaluating potential climate health impacts (41). Ecologic risk assessments look at the chance of adverse impacts on part or all of an ecosystem as a result of an exposure, such as pollution or development (31). In the context of health, ecologic risk assessment looks at how environmental change, such as given climate scenarios, in a particular ecologic context may influence human morbidity or mortality (41). The methodology of ecologic risk assessment is often similar to environmental impact analyses: relying on animal species data, computer-assisted geographic analysis, and expert judgment and opinion (31). A limitation of ecologic risk assessment with respect to human health impact assessment is that the association of human health with ecosystem health, although intuitive, is not clearly defined. Furthermore, the ecosystem for humans includes social, cultural, economic, and political systems, all of which play a role in the causal web of adverse population and individual health outcomes (48,49).

Finally, there is a growing emphasis on the use of integrated assessment in the climate change context (50). The term has been variously defined. Under one definition, “integrated assessment is an interdisciplinary process of combining, interpreting, and communicating knowledge from diverse scientific disciplines in such a way that the whole set of cause-effect interactions of a problem can be evaluated from a synoptic perspective with two characteristics: it should have added

value compared to single disciplinary oriented assessment; and it should provide useful information to decisionmakers” (51). Using this conceptualization, integrated assessment is a synthesis of knowledge across disciplines with the purpose of informing policy decisions rather than advancing knowledge for its intrinsic value. The outcome can be used to prioritize decision-relevant uncertainties and research needs. The methodology has proved useful in evaluating potential impacts of climate change other than human health impacts and is beginning to be applied to climate change and health issues (8). The main advantage of integrated assessment is that it can facilitate insights that may be difficult or impossible to achieve from traditional, single-disciplinary research. These insights can then be connected to the needs of decision makers. At the same time (and iteratively), the decision makers’ own experiences and needs inform the scientists (52). Examples of integrative assessment are the inclusion of pathogen transmission dynamics, ecologic forces such as changing land use, and demographic forces such as population movement into an evaluation of the potential impacts of climate change on infectious diseases (8). Integrated assessment also allows evaluation of how adaptation measures could change the system response. As with any type of risk assessment, choices must be made about variables to be included in the assessment (53).

Modeling is one of several methods employed to conduct an integrated assessment. An array of component models is developed, each with mathematical representations of cause–effect relationships. These are linked to show the interrelationships and feedback mechanisms among the key components. The resulting framework helps identify and prioritize scientific uncertainties. Sensitivity analyses can be conducted to understand better the sensitivity of the system to changes in each relationship (8). Although modeling can be useful for risk categorization, it can imply more precision than is appropriate where full data are absent, and relevant available data may be excluded or overemphasized. In addition, the technical limitations of the model might defeat the ultimate value of the analysis.

The Human Health Impacts Assessment

In keeping with the approach developed for the National Assessment, the specific goals of the health impacts assessment were to investigate the key determinants in the climate–health interaction, develop a research agenda, and identify appropriate current and future adaptation strategies. As noted, the health impacts assessment focused on the potential impacts of climate variability and change on

five health outcomes known to be associated with weather or ecologic change: temperature-related morbidity and mortality (3); injuries or illnesses from extreme weather events (4); air pollution-related health effects (5); water- and food-borne diseases (6); and vector- and rodent-borne diseases (7). Other possible health outcomes may be affected positively or negatively by projected climate change. Some of these are identified in the literature and in the health sector assessment summary (1). These outcomes may warrant more extensive future study.

For each health outcome, in keeping with the framework set out for the National Assessment as a whole (23), the health impacts assessment sought to address a set of questions:

- How might climate change affect the country’s health and existing or predicted stresses on health?
- What is the country’s capacity to adapt to climate change—for example, through modifications to the health infrastructure or by adopting specific adaptive mechanisms?
- What essential knowledge gaps must be filled to understand fully the possible impacts of climate variability and change on human health?

The health impacts assessment did not itself evaluate climate projections. Rather, it used the climate change projections developed for the National Assessment as an underlying set of assumptions. These projections were used only qualitatively, not quantitatively. The health impacts assessment did not incorporate the National Assessment socioeconomic projections in any quantitative or qualitative analysis. Such scenarios may be useful in future assessment efforts to facilitate modeling and quantitative projections. The health assessment group decided that the state of knowledge about health–climate relationships was not sufficient to support modeling that included the socioeconomic scenarios developed for the National Assessment. Indeed, no group used any socioeconomic projections other than economic and population trends (54). Where future population or other trends were relevant to the health impacts analysis, the appropriate projections were obtained independently [for example, McGeehin and Mirabelli discuss projected trends in future use of air-conditioning systems (3)].

The general approach used by the health sector was an integrated assessment across health disciplines, relying on the expert judgment of the panel members and those with whom they consulted, and incorporating where available some limited modeling of projected impacts of climate on health. In the assessment, the health sector group consulted with other experts and searched for and

reviewed hundreds of peer-reviewed studies, government reports, and limited ongoing research on the potential links between climate events, human exposures, and health impacts. These data came from *in vitro* and animal studies, some human clinical trials (e.g., studies of the effects of ozone exposure on human volunteers), and epidemiologic investigations. Some historical analogues were incorporated.

Analyses of the roles of population vulnerability and adaptation were woven throughout the assessment with respect to each health outcome. In the context of climate change and health, the vulnerability of a population can be defined as a function of the extent to which health, or the natural or social systems that affect health, are sensitive to changes in climate; the capacity of the population to adapt to new climate conditions; and exposure to the climate-related hazard (9,38). A system or population that cannot or will not adapt is more vulnerable, as is one that is susceptible to even slight changes in climate. Vulnerability of a population to a health risk in general depends on such factors as population density, level of economic and technological development, local environmental conditions, preexisting health status, and the quality and availability of health care and of a public health infrastructure. These factors are not uniform across the nation. Rather, there are geographic, demographic, and socioeconomic differences among various regions. Underlying the analyses of the five health outcomes is the estimation of the health sector group that certain populations within the United States may be more vulnerable to certain health risks that might initially be exacerbated by climate change. Poverty, for example, is a risk factor for heat-related illnesses and deaths, because the poor are more likely to live in urban areas and are less likely to be able to afford air conditioning (3). Poverty can exacerbate health problems in the elderly, who are vulnerable to the adverse impacts of heat. Understanding what demographic or geographic subpopulations may be most at risk is critical to the effective targeting of prevention or adaptation strategies. For example, making air-conditioned environments readily available and affordable to the poor, urban elderly is an adaptive response strategy to reduce illnesses and deaths in heat waves.

In addition to its relevance as a component of a vulnerability analysis, each region and sector was specifically required by the National Assessment plan to identify adaptation measures [“coping options” (23)] in response to potential climate change. Adaptation in the context of human health involves the ability to change human behavior and to modify health and other types of

infrastructure (including, for example, housing, transportation, energy, and water and wastewater systems) to reduce potential negative impacts or to increase potential positive impacts of an event. Adaptation is a function of numerous societal variables, including financial resources, technical knowledge, public health infrastructure, and capacity of the health care system, all of which depend to some degree on competing demands and on the political, social, and economic climate. Adaptation can be anticipatory (actions taken in advance of climate change) or responsive and can encompass both spontaneous responses to climate change by affected individuals and planned responses by governments or other institutions.

Of course, humans have always adapted to their immediate environment to protect their health and well-being. But climate change presents new challenges beyond those addressed by different societies in their evolving response to environmental threats to health. First, there is the possibility of real and unpredicted changes that vary significantly from an accepted range of normal within a location. Second, the process (and speed) of change may diverge from the established pace of such change in the past. Adaptation measures, past and future, affect the need for future adaptation measures. In general, measures to adapt to the potential impacts of climate change can be expected to vary in effectiveness, to have both beneficial and deleterious effects, and to come at a cost (55). For example, air conditioners can reduce the risk of persons dying in a heat wave; but, assuming a continuation of present fossil-fuel energy sources and technology, air conditioners are energy consuming and expensive and contribute to anthropogenic greenhouse gas emissions. Adaptation strategies should target current areas of economic opportunity and complement adaptation initiatives pursued to address potential impacts of climate change on other sectors such as water or coastal resources (56,57).

Generally, the adaptation measures identified in the health impacts assessment, such as heat-wave planning and vector-borne disease surveillance programs, are recognized by the public health community as important to the protection of lives and health regardless of future climate change. Climate change projections may help prioritize these measures, but their current importance suggests that in developing adaptation strategies many projections may be considered win-win, i.e., beneficial, even if they prove inaccurate. On the other hand, the fact that these measures are often necessary anyway does not mean that investigation of potential future climate change impacts is pointless, because the additional stresses (or reduction in stresses)

brought about by climate change may raise or lower the need for the adaptation measures. As just one example, flood risk in an area might change (58), requiring modification to emergency planning and prevention measures to prevent injuries and illnesses.

Mitigation, or primary prevention, is a climate change response strategy distinct from adaptation. The scope of the National Assessment, as planned by the NAST and approved by the SGCR and the NSTC, did not encompass investigation into the specific role of anthropogenic contributions to climate change or the identification of measures to prevent or delay emissions of greenhouse gases or to reduce levels of greenhouse gases in the atmosphere (e.g., through carbon dioxide sequestration). In keeping with the overall National Assessment plan, the health sector assessment did not address mitigation, although it recognized that adaptation for impacts associated most directly with energy consumption (e.g., air pollution) can increase or decrease emissions of greenhouse gases (5). Part of the context of the National Assessment is that mitigation strategies are the focus of other past and ongoing research and programs in the United States and elsewhere, particularly through the Intergovernmental Panel on Climate Change (9). Parallel research on adaptation measures is important, because the extent and success of current and future mitigation measures are uncertain. In addition, climate scientists project that some degree of climate change over the next several decades cannot be prevented, as a result of already elevated concentrations of greenhouse gases in the atmosphere, even if mitigation steps are taken. Looking at adaptive capacity helps develop a local-to-national, bottom-up (52) discussion about how institutions can learn to monitor for anticipated and unanticipated changes and respond appropriately. Emphasizing development of flexible and responsive adaptive capacity will help communities respond both to current climate patterns and to future changes without depending on development of improved capacity to project either regional-scale climate change or associated impacts (59). Future climate change assessments might choose to link adaptation and mitigation research and impacts.

As did the larger national effort, the health impacts assessment involved layers of expert, stakeholder, and public review and comment. Expert review occurred throughout the assessment. Drafts of the health impacts assessment report were reviewed in three stages by 19 individuals with expertise in one or more of the health subject areas discussed. Each expert reviewed either an individual section (i.e., article) or the entire document.

The health sector defined its stakeholders as people within private, nonprofit, and government entities (local, state, federal) focused specifically on public health issues. This definition is consistent with the common understanding of the word *stakeholder* as an individual or organization with an interest, experience, or prior involvement or investment in an issue (32). Early comments on the assessment were solicited by mail from a preliminary list of about 445 individuals and organizations from government, nonprofit groups, academic institutions, and private entities, including a small number of individuals, international organizations, and media representatives. Indirect solicitation of public (and stakeholder) involvement was accomplished through notices about the health impacts assessment outline draft and about later report drafts, which were distributed on various climate change Internet e-mail servers, including the climate change list server of the U.S. EPA and the list server used by the National Assessment Coordinating Office to communicate with all National Assessment participants. The public and stakeholders also contacted the health sector group after learning about the assessment through general media sources, the web site of the Johns Hopkins Program on Global Environmental Change, other web sites that carried information about the health impacts assessment, or conferences and presentations. All written stakeholder and public comments on the outline and section drafts were reviewed and responded to. Information about expert, stakeholder, and public comments and responses are posted at a web site set up for the health impacts assessment at <http://www.jhsph.edu/nationalassessment-health>.

An important component of the health impacts assessment was the identification and recognition of the several layers of uncertainty inherent in the type of "if . . . then" questions asked by the National Assessment. Response to these questions can be characterized not as prediction, but rather as a type of vulnerability analysis (23) that calls for a deductive, not inductive, process (41). Uncertainties begin with the climate models themselves. These models are uncertain because of factors such as the complexity of climate systems, the possibility of nonlinear responses to changing greenhouse gas concentrations, variations in assumptions/model input, and lack of resolution at the regional and national levels (10). There is also uncertainty in how climate affects biologic and physical systems (now and in the future), how health impacts would be mediated by changes to other systems or processes such as water supply (41), and what deliberate or fortuitous adaptations would exist. It is impossible to know with any certainty how people will live in 25–100 years or

what the leading causes of morbidity and mortality will be, nor the size of the population, the status of the economy, or the primary energy sources. There are uncertainties in statistical methods used to analyze data and in mathematical modeling used to make projections when data are not available. Finally, there are uncertainties in the fundamental health data. For example, questions may arise about the validity of extrapolating certain animal data to humans, and there is the potential for bias, confounding, or misclassification in the collection, analysis, and interpretation of epidemiologic data. The existence of these layers of uncertainty does not invalidate critical efforts to anticipate potential future public health impacts of climate change or of comparable projected risks, but it is important for scientists, policy makers, and the public to recognize their existence, to be realistic about the likelihood that they can be resolved in a meaningful time frame, and to understand their significance both to future research directions and to policy making.

Consider, as an example, the value and limitations of the National Assessment requirement that each region and sector evaluate the current status of and important stresses on the sector or region. Present health patterns—including a higher overall life expectancy in the United States than ever before, the predominance of chronic diseases over injury and infectious disease as a cause of death, and health disparities among gender, racial, and economic groups in morbidity and mortality patterns (60)—are unlikely to be familiar to public health practitioners 50–100 years from now (except in historical texts). It is well established that social, economic, political, environmental, and technologic factors have a strong impact on health. Urbanization; funding for public health infrastructure (e.g., sanitation systems and medical research); scientific developments; public health interventions; shifts in public attitude, behavior, or policy; and the emergence or reemergence of infectious diseases all affected population health status in the past and can be expected to do so in the future. The complexity of these determinants to health is such that future projections about stresses on population health, including but not limited to projections concerning the potential impacts of climate variability and change on health, become increasingly uncertain with expanding timelines. An example is the uncertainty about the proportion of the population likely to be most vulnerable to potential health impacts of climate change. Currently, the people most vulnerable to the health outcomes analyzed by the health sector group include the very old, the very young, the immunocompromised, and the poor. Estimates of the proportion of the population

within these groups become less certain over time. Short-term projections are relatively certain. For example, in 2010, when the first of the baby boom generation reach 65 years of age, the elderly will make up 13.2% of the population (39.4 million), and by 2030 that proportion will rise to 20% (61). A major factor in the rising proportion of elderly is large increases in the number of people surviving past 85 years of age; that population group is expected to double in size from 1995 to 2030 and to increase 5-fold by 2050 (61). Thus, there will be more people in the 65-and-over and 85-and-over age groups who are potentially vulnerable to heat waves over the next 25–50 years because of the size and current life expectancy of the population group now in the 40- to 60-year-old range and because of the presently greater risk of morbidity and mortality during heat waves for the elderly (3). In the 100-year time frame, however, it is less certain whether the proportion of the population considered elderly will be as high as it is projected to be in the near term. For both time frames, interacting/modifying risk factors in the age/heat-related illness association (such as poverty, urban residence, and lack of access to air-conditioned environments) and deliberate or unintended adaptation measures could play an important part in exacerbating or minimizing future heat-related morbidity and mortality in this age group.

Unanticipated events can dramatically change population health outlook. Although the role of some known threats to health can be estimated in the near term, unanticipated health threats that will be significant to the potential impacts of climate change are likely. Consider that among those considered vulnerable to the effects of climate change are immunocompromised individuals. Currently, a growing proportion of the immunocompromised in the United States are infected with human immunodeficiency virus (HIV), the cause of acquired immune deficiency syndrome, a disease that was unheard of before 1981 (62). In 1995, HIV infection was the leading cause of death for 25- to 44-year-olds, but by 1996 it had dropped to the third leading cause of death because of improved survival rates (60).

Even factors such as life expectancy and the capacity of the public health infrastructure may change in the event of epidemic disease or social disorder. Approximately 500,000 Americans died during the Spanish influenza pandemic of 1918 that killed more than 20 million people globally (63). About 25% of the general population in the United States became ill, and about 40% of the armed forces were ill. The fatality rate averaged about 2.5%. Life expectancy in the

United States dropped from 51 years in 1917 to 39 years in 1918 (64).

A more recent example is the rapid negative impact on population health of the social, political, and economic changes in the Russian Federation following the collapse of the Soviet Union. This decline in the country's health was characterized by decreased availability of health services, outbreaks of infectious diseases, and unprecedented declines in life expectancy (65,66). Male life expectancy fell by more than 6 years, from 63.8 years in 1990 to 57.7 years in 1994; female life expectancy declined by more than 3 years to 71.2 years in 1994 (66). Between 1990 and 1994, mortality rates rose for every age group in both sexes, with the largest increases in the 35- to 44-year-old group (66). These changes resulted from a complex web of variables that have not yet been fully identified, and precise quantitation of them is hampered by data problems (65,66). However, they illustrate how dependent health status is on external variables, including economic, political, and social conditions. Poverty may be one factor (the number of Russian families living in poverty rose from 2% in 1987 to 38% in 1993), but the relationship between poverty and mortality in Russia appears complex. The areas that suffered the highest mortality increases were urban areas that became most unequal in socioeconomic terms and had the greatest increases in crime (67). Another probable factor is a rise in alcohol consumption, including an increase in consumption of homemade, more toxic alcohol (65). Other, probably less significant, factors included increased smoking levels, poor nutrition, stress, depression, and a declining health care system (65,66).

Conclusion

The health impacts assessment is reported in separate articles in this issue of *Environmental Health Perspectives*. In each article, the authors attempted to elucidate scientific uncertainties, describe some adaptation measures currently in place or available, and identify future research needs and data gaps. We hope that this set of articles will enhance public and political understanding both of how human health might be affected now and in the future by various climate-associated stresses and of the limitations of the knowledge base (68)—the extent to which data have not yet been obtained or may prove elusive despite further research effort. Further empirical and predictive research is necessary to improve our understanding of the connection between climate and health and of the possible consequences of climate change on health.

Developing methods to anticipate better the range of likely potential consequences of

global environmental change (a category that includes loss of biodiversity, depletion of stratospheric ozone, deforestation, depletion of fresh water resources, and other ecologic concerns) through interdisciplinary research will be important in helping avert some anticipated consequences (37). Improved projections of future climate change and of its potential impacts can help to ensure that adaptation measures are appropriate and effective. In addition, the health sector assessment identified some research gaps in basic scientific knowledge about the relationships between climate and health that can be addressed without the need to improve predictive capacity. Empirical research to answer these questions can then be used to enhance projections and improve qualitative and quantitative risk assessment. Research in climate change similarly influences research in other sectors such as species loss or migration and habitat degradation (52).

However, even valuable and timely new data will not provide conclusive answers to questions about the probability or magnitude of potential harm or benefit to human health in the United States if projected climate change scenarios are realized. Thus, science and policy must be iterative in this process, not sequential. Policy decisions—such as the location on the probability distribution of a final answer in a risk assessment at which a decision maker should take action (53); the establishment of priorities among adaptation or mitigation measures and among climate change and competing societal challenges (and indeed, between research funding and funding for adaptation or mitigation measures); and the decision to avoid or invest in precautionary adaptive measures—can be guided, but not answered, by scientific research and by scientific interpretation of the uncertainties inherent in that research. Information in assessing the public health value of adaptive measures, even without projected climate change, may be important to policy makers and may warrant separate further interdisciplinary investigation among health scientists and risk managers with the participation of other stakeholders such as local governments.

Historically, two important variables drive public health strategies: the level of scientific and technical knowledge, and the content of public values and popular opinion (63). Management of environmental risks, a public health strategy, is “the process by which risk assessment results are integrated with other information to make decisions about the need for, method of, and extent of risk reduction” (31). In the context of climate change, decisions about what, if anything, to do with the information currently available (including that provided by the health impacts assessment),

even as critical research continues to fill in the answers, is up to policy makers working with scientific, stakeholder, and public input. An important component of the role of scientists in this regard is explaining the role of uncertainty in the scientific process and contrasting it to the role uncertainty may play in policy development.

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